The Challenges of Developing a Food System for a Mars Mission

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Space Food Systems Lab Facility Capabilities: Flight Food Provisioning and Research

JSC Research and Development Capabilities:

Develop, produce, package, stow, and ship all thermostabilized and freeze-dried foods and package, stow, and ship all COTS drinks and foods per spaceflight requirements for USOS International Space Station Crew Members.

- JSC: Pilot plant-sized freeze dryers, mixer, standard kitchen equipment, convection oven, canning and vacuum packaging, packaging equipment for freeze-dried foods, bite sized and low moisture COTS foods, beverages, and stowage. JSC Micro Lab confirms safety.
- Space Food Research Facility – Texas A&M University, College Station, TX: Pouch-compatible retort with access to process authority, pilot plant-sized freeze dryer, mixers, kettles, retort pouch packaging equipment, standard kitchen equipment.

Menu Development for nutritional requirements and variety

- Use of food nutrient database
- Macronutrient and mineral analysis from JSC Water and Food Analytical Lab (Micronutrients outsourced)

Research and Analyses

- Focused in-house on shelf life testing, optimization of formulation, quality, and nutritional stability, and analysis of new technologies and packaging.

Food System Considerations

Current International Space Station Food System:

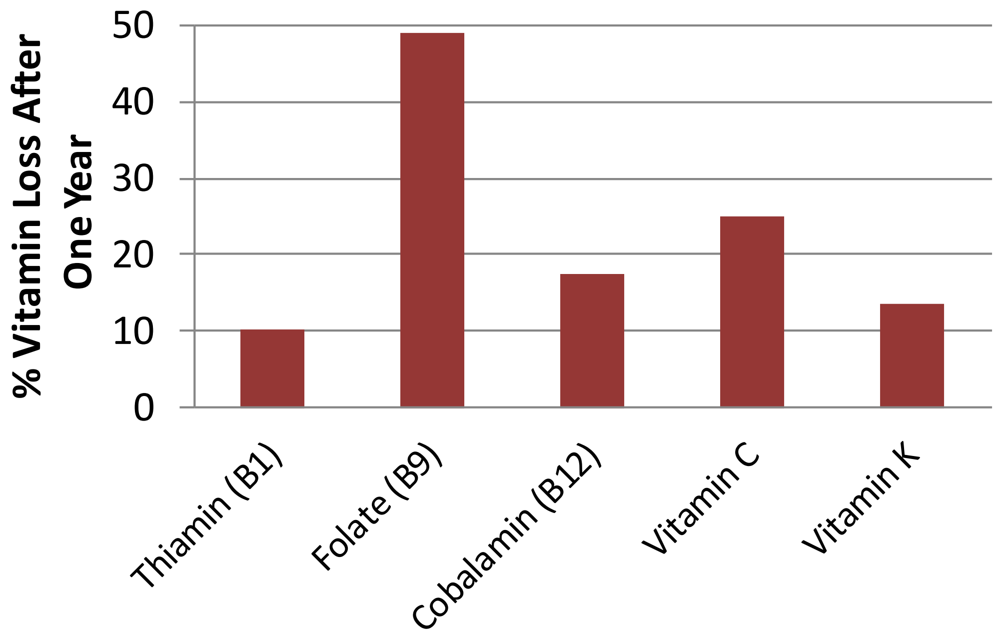
- No refrigerators or freezers for food storage
- All food processed and prepackaged
- Eight day menu cycle for six month missions on International Space Station
- Standard food and drink options (203) are augmented by processed and prepackaged “bonus” requests from crew
- Fresh food only sporadically available at resupply

Mars Expedition Scenario

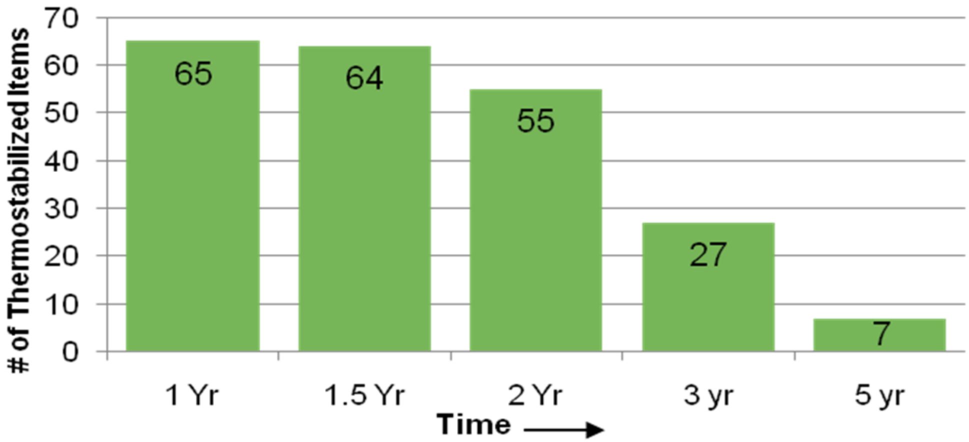
- Approximately 2.5 year mission with segments in microgravity, reduced gravity, and variable pressures
- No refrigerators and freezers
- No resupply
- Prepackaged foods may be prepositioned to accommodate high mass and volume
- Production, stowage, and prepositioning lead time may result in requirement for 5 year food shelf life

Nutrition and Acceptability Impacts of Room Temperature Storage

- Micronutrient content of 109 spaceflight foods shows significant degradation in several critical vitamins following one year of ambient temperature storage.



- Only 7 out of 65 thermostabilized foods are expected to be palatable after 5 years of ambient temperature storage. (Catauro. JFS. 2011)



AFT Gaps and Relationship Diagram

The goal of AFT is to identify the methods, technologies, and requirements that will provide a safe, nutritious, and acceptable food system in balance with its use of constrained vehicle resources such as mass, volume, power, and crew time for exploration missions.

AFT1 - Knowledge Gap
We need to determine how processing and storage affect the nutritional content of the food system.

AFT3 - Knowledge Gap
We need to determine how the sensory and psychosocial acceptability of the food system changes due to microgravity, processing, storage, choice, and eating environment.

AFT4 - Mitigation Gap
We need to identify the methods, technologies, and requirements that will deliver a food system that provides adequate safety, nutrition, and acceptability for proposed long-duration Design Reference Mission operations.

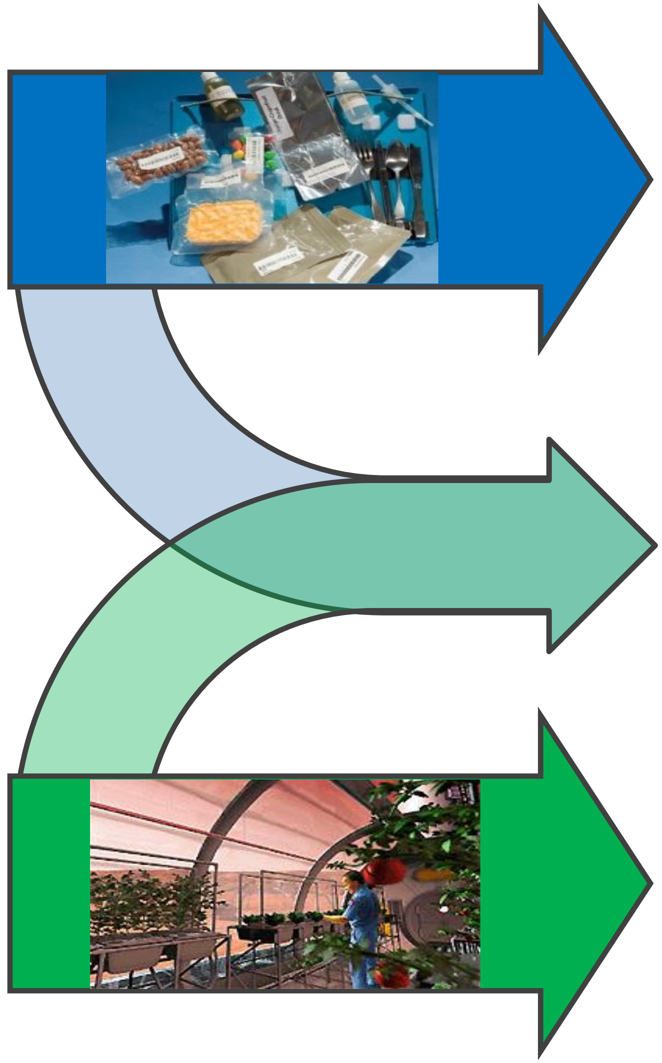
AFT5 - Disposition Gap
We need to identify tools or methods that can be used or developed to help mission planners and vehicle developers determine the most effective combination of methods, technologies, and requirements to balance crew food system needs with vehicle resources.

Possible Food Systems for Surface Mission

Prepackaged Foods Only

Prepackaged and Bioregenerative Combo

Bioregenerative & Bulk Ingredients Only



<u>Key Assumptions</u>

Product development and storage conditions are presumed to deliver feasible food shelf life.

Only existing products with a shelf life > 3 years are used to supplement the below bioregenerative menu.

15 different crops (including soybeans and tomatoes) and 11 bulk ingredients shipped from Earth (plus minors) are used in menu development and analysis.

Prepackaged vs. Bioregenerative

- Use of metrics to compare food systems:
  - Equivalent System Mass (Levri 2003, NASA/TM– 2003–212278)
    - Quantitative evaluation metric enabling comparison between systems
    - Converts mass, volume, power requirements, and crew time into one value
  - Modified Food Quality Index (MFQI) function (Cruthirds 2002 ICES)
    - Accounts for the nutritional value, palatability, and menu cycle length

- Recent metric evaluation indicates that the optimal food system would combine prepackaged and bioregenerative
  - Future work: Determine how to efficiently combine the systems

Prepackaged Food – 5 Year Shelf Life Challenge

Processing

PATS Processed Apples | **Retort Processed Apples**

Pressure Assisted Thermal Sterilization (PATS)

Microwave Sterilization

Packaging

Improve clarity

Improve barrier

Mass reduction

Formulation

Fortification

Food Matrix

Functional Foods

Environment

21°C | **-80°C**

Storage Conditions

Temperature

Radiation

Current Food System Mass and Volume Impacts

Avg. ~3000 kcal/person/day + current primary packaging

Mass:
1.83 kg/crewmember/day
Volume:
0.00472 m3/crewmember/day

Food for 1095 days, 6 crewmembers

Total Mass: 12,023 kg
Total Volume: 31 m^3

Prepackaged Food - Mass and Delivery Challenges

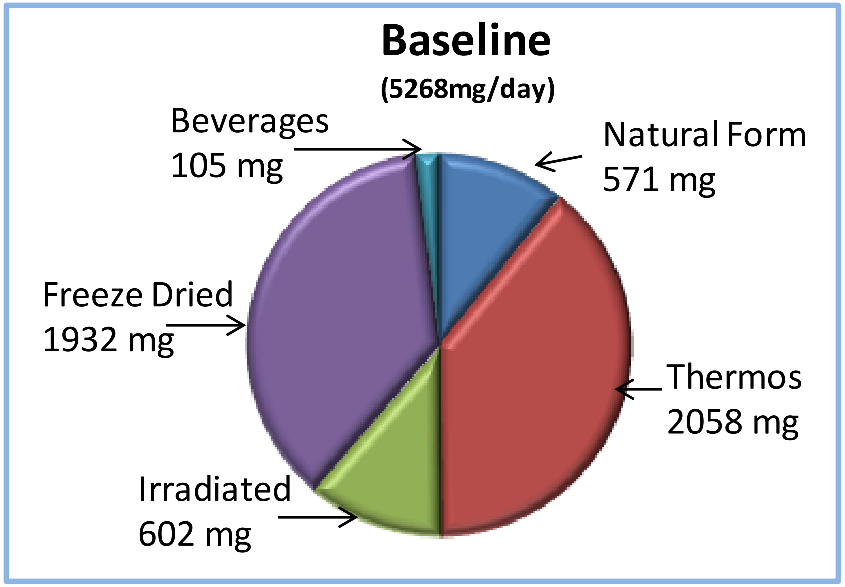
- In-suit nutrition delivery
  - Contingency during emergency – 144 return in pressurized suit
  - Extra-Vehicular Activity (EVA)

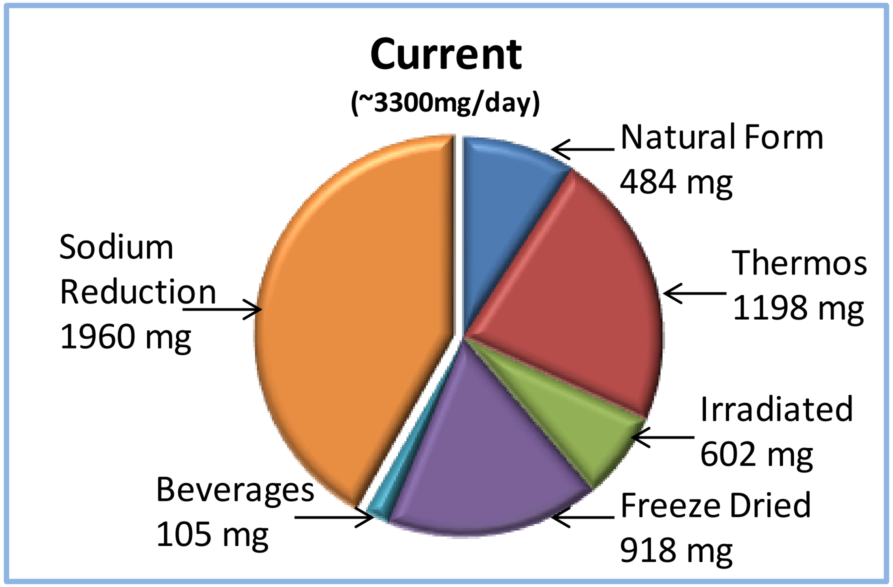
Prepackaged Food – Sodium Reduction Challenge

- Complete diet of prepackaged shelf-stable food was high in sodium (5300 mg/d)
  - Exacerbates bone loss
  - Potential exacerbating factor in intracranial pressure induced vision changes
- Project Objective
  - Reduce sodium content of standard menu to 3000 mg/d
- Sodium Reduction Strategy
  - Reformulated 90 foods on current menu; utilized herbs/spices to compensate for reduced sodium
  - Removed salt from all processes (i.e. blanching), switched to salt-free snack items where available
  - Sensory evaluation: must score 6.0 on 9.0 Hedonic scale

Sodium Reduction Challenge - Conclusion

- Reduced sodium content to ~3300 mg/d
- Maintained sensory acceptability similar to or better than original formulations





Bioregenerative

- Benefits
  - Lower food stowage mass
  - Fresh food/improved nutrition and acceptability
  - Personalized preparation increases food variety/acceptability
  - Psychosocial benefit of agricultural activity
  - Potential for bioregeneration of gases in closed habitat

Bioregenerative Food System Challenge

- Optimization for phased implementation – based on nutrition, acceptability, feasibility, resource use
- Plant chamber infrastructure / resource use and effect on other systems
- Effect of radiation on nutrition and acceptability / loss of crop
- Safe handling / low impact micro testing procedures
- Effect of storage conditions on functionality of stored ingredients
- Optimization of menu development / variety / galley infrastructure
- Processing and preparation procedures / equipment / crew time

Bioregenerative Crops and Bulk Ingredients

- Greenhouse Crops

Lettuce	Bell Pepper
Spinach	Mushrooms
Celery	Peas
Green Onion	Snap Beans
Carrot	Sweet Potato
Tomato	White Potato
Strawberry	Radish

- Bulk Ingredients

Rice	Peanuts
Dry Beans	Peanut Oil
Wheat Berries	Wheat Flour
Soybeans	

**No Animal Protein

Food Processing/Preparation Equipment

- Equipment should be versatile:
  - process foods safely in hypobaric and hypogravity environment.
  - be multi-use, reduce mass/volume
  - be easy to use, maintain, and clean
- Examples of equipment needed:
  - Soybeans to tofu
  - Wheat berries to bread

Soymilk, tofu, okara and whey processor (STOW)

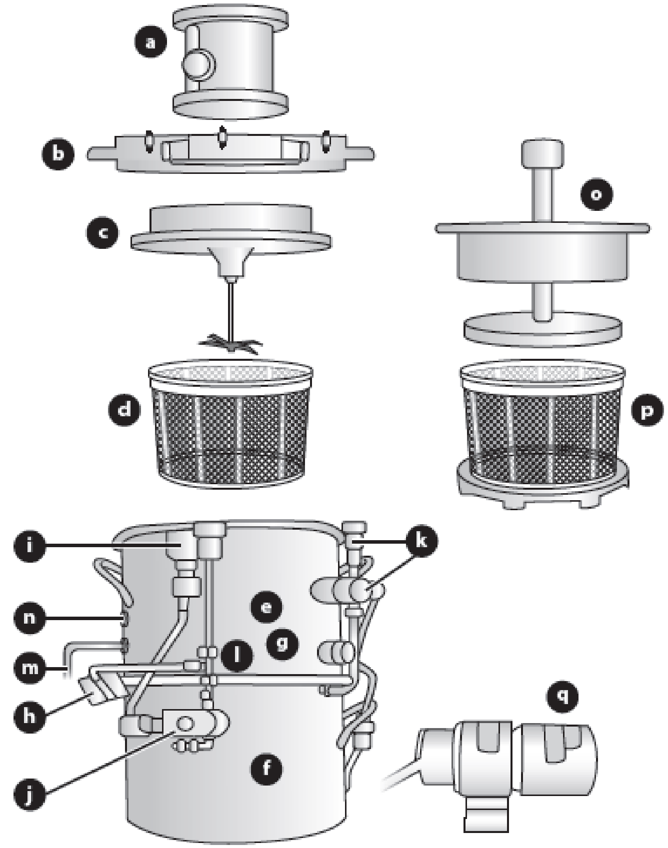


Figure 1

Diagram of soybean, tofu, okara, and whey processor: (*a*) grinder motor, (*b*) process tank lid, (*c*) grinding blade assembly, (*d*) filtration basket, (*e*) process tank, (*f*) coagulation tank, (*g*) inlet valve (rear of tank), (*h*) flow meter, (*i*) process tank valve, (*j*) coagulation tank valve, (*k*) coagulant solution inlet and valve, (*l*) heating element connection (rear of tank), (*m*) process tank temperature probe connection, (*n*) process tank drain valve connection, (*o*) manual press head, (*p*) curd filtration tank, and (*q*) transfer pump.

Perchonok et al. 2011. Annu. Rev. Food Sci. Technol.

Recent Menu Development Project

- Nutrition
  - Developed 90 recipes that met macronutrient requirement for 10 day menu cycle

	Recommended Level NASA Requirements
Calories	3035
Carbohydrates	50 - 55% of energy: 379 – 417 g
Fat	25 - 35% of energy: 84 – 118 g
Protein	15 – 30% of energy: ≤ 118 g
Fiber	30.3 – 42.5 g

- Acceptability
  - Averaged 7.45 on a 9.0 Hedonic scale
- Crew time
  - Meal preparation averaged between **6.5 to 7.5 hours a day**

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Questions